THE MOVEMENTS AND THE INNERVATION OF THE LARGE INTESTINE. By W. M. BAYLISS AND E. H. STARLING. (Nine Figures in Text.)

I. THE LARGE INTESTINE OF THE DOG.

OUR main object in investigating the activity of the large intestine, after the very accurate account of the innervation of this organ by Langley and Anderson[1], was rather to see how far the local reflexes present in the small intestine played a part also in the normal life of the large intestine. Since here, as in our previous work, we have made large use of the graphic method, we have taken the opportunity of reinvestigating the action of the extrinsic nerves of the gut by this method.

By the large intestine in this paper is understood the portion of the gut between the ileocæcal valve and the attachment of the levator ani muscle; the anal canal, which is more intimately dependent on its connection with the central nervous system, being left out of account.

Methods. The animals were in all cases anæsthetised, generally with morphia and A.C.E. mixture. In a few cases the morphia was omitted, but in these cases the gut was not found to be more active than in the others. In all cases the muscular wall of the gut was cut through at the level of the attachment of the levator ani, in order to avoid the shifting of the whole gut into the pelvis which is produced by contraction of the recto-coccygeal muscles. A dose of castor oil was administered the day before the experiment. In most cases the small intestine was also cut through just above the ileocæcal valve, and the whole colon washed through with normal salt solution. The balloon which was connected with the recording tambour was introduced into the gut through the lower opening, or through the ileocæcal valve, or more rarely through a small incision in the wall of the gut.

The separation of the gut from the central nervous system was

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carried out in one of two ways. Langley and Anderson have shown that the colon receives its nerves from two sources, from the upper lumbar nerve roots through the sympathetic chain and inferior mesenteric ganglion, and from the sacral nerve roots by way of the pelvic visceral nerves. The influence of the central nervous system on the colon would, therefore, be abolished either by destruction of the spinal cord below the tenth dorsal vertebra, or by extirpation of the inferior mesenteric ganglia combined with section of the pelvic nerves. Both methods were employed. The destruction of the lower end of the cord was generally accompanied with section of both splanchnic nerves in order to be absolutely certain of abolishing all possible connections through the sympathetic between colon and spinal cord. When the method of extirpating the nerves in the abdomen was employed, the small intestine was divided above the ileocæcal valve, and the mesentery slit up so as to leave the gut attached only by its vessels, which had previously been cleaned of all their nerve filaments.

In view of the possibility of the sympathetic ganglia, *i.e.* the inferior mesenteric and the pelvic ganglia, having reflex functions, we have looked carefully for a difference in the behaviour of the gut after enervation by the two methods described, but have not found that retention of the connections of the colon with the pelvic and mesenteric ganglia alters in any way its behaviour from that of the colon in which the ganglionic connections have been destroyed.

The activity of the enervated colon. On exposing the large intestine in the warm saline bath, 30 or 40 minutes after the completion of the preliminary operations, it is generally seen to be in a state of moderate constriction. Spontaneous descending contractions of the gut are rarely noticeable on simple inspection. If the small intestine be in an active condition, peristaltic contractions are occasionally seen which pass down the ileum and, if its connection with the colon be not destroyed, pass over the ileocæcal junction to the colon. Such a peristaltic wave may be produced at will by the insertion of a bolus of cotton wool and soft soap into the small intestine. The bolus is driven into the colon and down it for some distance, but the peristaltic wave as a rule dies away at about the middle of the colon or the beginning of its descending part, and if several boluses be inserted one after the other, they all tend to accumulate about this part of the colon. In some cases, with an active colon, the accumulation at this part excites a peristaltic wave which drives the accumulated mass down the whole of the descending colon and out of the lower orifice.

On inserting the recording balloon into the colon, we find as a rule that this viscus is the seat of rhythmic contractions, which starting above the balloon appear to travel downwards. These contractions are quite different in character from the rhythmic beat of the small intestine; they are much larger and of less frequency, and each contraction may last from 10 to 40 seconds. Superposed on these large contractions may be generally seen smaller ones, not very regular but having an individual duration of 2 to 4 seconds. We have not been able to decide definitely where there is any fundamental difference in the mode of origin of these two classes of contractions, whether, for example, the large contractions are neurogenic, and the small superposed waves myogenic in origin.

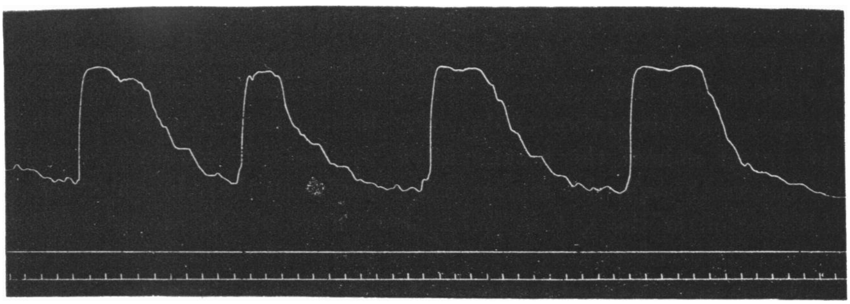

Fig. 1. Dog. All nerves cut. Spontaneous activity. Time marking = 6 seconds.

One meets, however, with extreme variations in the activity of the muscular wall of the colon. In some cases it enters into a state of tonic contraction, presenting no mark of rhythmic action; in other cases (more rarely) it is perfectly inactive and in a position of complete relaxation.

Local reflexes. 1. *Descending inhibition.* As in the small intes-

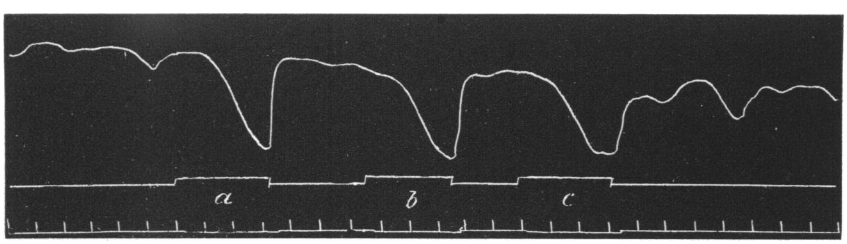

Fig. 2. Dog. Colon. Showing descending inhibition. All nerves cut. At (*a*) and (*b*) pinch small intestine, at (*c*) pinch large intestine above balloon.

tine of the dog, so in the large, it is extremely easy, after complete destruction of its nervous connections, to evoke a descending inhibition. A stimulus, such as a pinch, applied to any part of the colon, or even to the lower part of the ileum, produces at once complete inhibition of the whole of the colon below the stimulated point.

In the experiment from which Fig. 2 was taken, the large intestine was in a state of tonic contraction with very slight rhythmic intermissions. It will be seen that each stimulation above the position of the balloon, either of the lower part of the ileum or of the colon two inches above the balloon, produced a relaxation of the muscular wall of the gut. The same inhibitory effect occurs below a descending peristaltic wave, so that the effect of a series of peristaltic waves dying away, as they generally do, at the beginning of the descending part of the colon, must be to distend more and more this part of the colon. We have already seen that in a particularly active gut this accumulation may result in the production of the peristaltic wave in the descending colon, and an emptying of this portion of the gut. It is probable, however, that in the intact animal the accumulation in this situation excites motor discharges through the lumbar spinal cord, and that the emptying of this portion of the gut is under the control of the central nervous system. In no case after complete enervation of the gut is an ascending inhibition ever observed as the result of local stimulation.

2. *Ascending excitation.* As we should expect from the greater sluggishness of the large as compared with the small intestine, it is much more difficult in the former to evoke evidence of an ascending excitatory change as the result of local stimulation. On many occasions we have been unable to obtain any contraction by stimulation of the gut immediately below the recording balloon, the descending inhibition

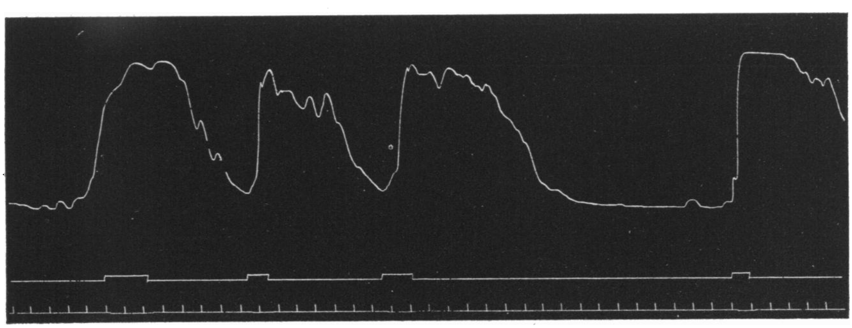

Fig. 3. Dog. Colon. Excitation by stimulating (pinching) below.

due to the presence of the balloon being more than sufficient to counteract the excitatory effects of the local stimulation. In some cases, however, especially if the balloon be in the upper region of the colon, pinching the intestine half an inch below the balloon may evoke contractions over the balloon (Fig. 3).

In this experiment the intestine was in a state of relaxation, and it will be observed that each stimulation is followed by a typical prolonged contraction. In the same region of the gut it is generally possible by the insertion of a bolus, moistened with soft soap, to assure oneself of the existence of an ascending excitation from the stimulated point. A band of constriction appears in the gut above the bolus, and gradually spreads down towards the middle of the colon, driving the bolus in front of it.

Extrinsic innervation of the colon. Here, as in the small intestine, we find that different writers have made the most diverse statements. For this divergence in results, we believe four factors are responsible.

1. The integrity of the central connections allowing confusion to arise between directly excited and reflexly excited changes.

2. Exposure of the gut leading to cooling and drying, or involving unnecessary handling of the viscus.

3. The use of the method of inspection unchecked by graphic records.

4. The bias of a preconceived theory.

In our experiments on this question we have obtained invariable and perfectly definite results, and these results could be obtained with

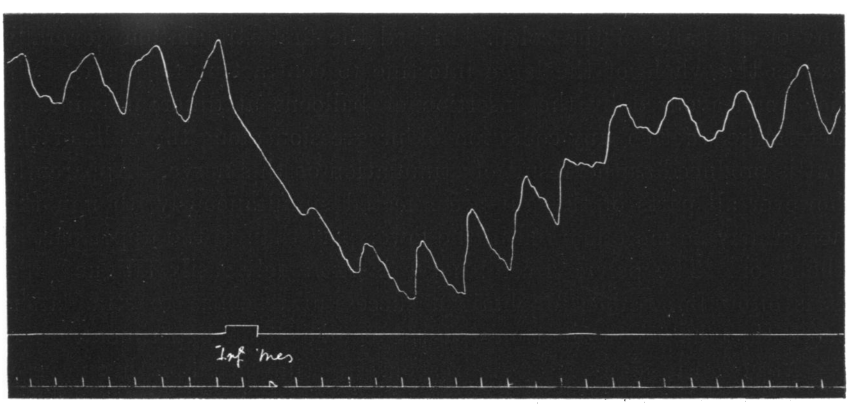

Fig. 4. Dog. Colon. Stimulation of inferior mesenteric nerve below ganglion.

extreme ease by any other physiologists employing the same precautions, *i.e.* the complete separation, muscular and nervous, of the colon from the rest of the body leaving it attached only by its blood vessels, the use of the warm saline bath, and the employment of the graphic method. Of course this last, being merely another mode of inspection, is rather an aid to experiment than an essential condition of the experiment. It has the advantage, however, that it involves the introduction into the large intestine of a balloon which excites this viscus to a constant state of moderate activity, and it enables us to judge of the time relations of any reaction to experimental interference.

Action of the sympathetic supply on the colon. We have stimulated these nerves in two situations: before entering the inferior mesenteric ganglion (where they may be spoken of as the colonic splanchnics) or after passing through the ganglion as they course along the inferior mesenteric vessels. The effect is the same in the two cases, *i.e.* a marked inhibition of tone of the colon accompanied by a cessation of the rhythmic contractions. The diminution in tone may last for some time after the re-establishment of the rhythmic contractions. We have never observed any trace of a motor effect of these nerves on either coat of the gut. Both circular and longitudinal muscles seem to be equally inhibited. We have not observed any after augmentor effect as the result of stimulating these nerves. Fatigue of these nerves is not easily produced; they may be excited again and again, especially in their post-ganglionic course, without any diminution in their effects being apparent.

Pelvic visceral nerve. This nerve is the motor nerve to the whole colon. Stimulation of either nerve may cause a contraction at any or all parts of the colon. Indeed the first stimulation generally causes the whole of the large intestine to contract up to a cord. We have endeavoured by the insertion of balloons at different points to determine whether any condition of progression along the walls of the gut is produced as the result of stimulation of this nerve. Apparently however all parts of the gut are affected simultaneously, though the action may be more marked in the lower part than in the upper part of the colon. The pelvic visceral nerve is extremely easily fatigued, and it is often impossible to obtain a successful response to stimulation more than half a dozen times in the course of an experiment.

Although in many cases the response to stimulation of this nerve is directly augmentor, in the majority of cases, especially if the intestine be in a state of tone, the first effect is an initial inhibition which is followed by the augmentation. These two types of response are shown in Figs. 5 and 6.

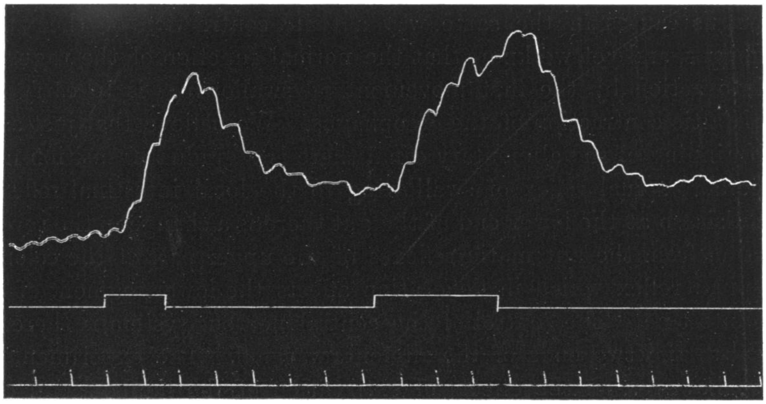

Fig. 5. Dog. Colon. Stimulation of pelvic nerve (right side, coil at 10).

This initial inhibition is exactly analogous to that which is found in this animal in the small intestine as the result of stimulation of the vagus, and, as in this case, we are inclined to ascribe it to a descending inhibition resulting from contraction of the gut some distance above the balloon, and regard it therefore, though initial, as only a secondary or mediate effect of the stimulation of the nerve.

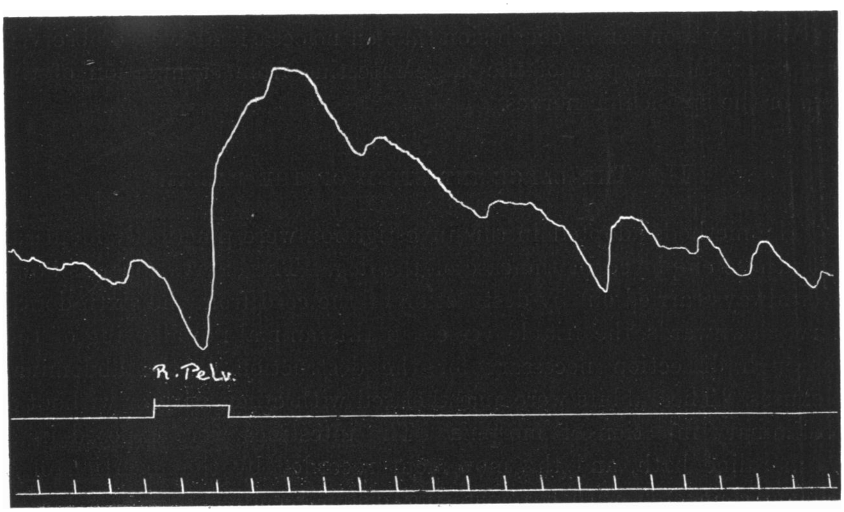

Fig. 6. Dog. Colon. Stimulation of pelvic nerve.

The fact that stimulation of the pelvic nerve generally evokes a simultaneous contraction of the whole colon does not of course signify that this is the normal mode of activity of the nerve. Stimulation of the vagus causes in the same way a tonic contraction of the whole œsophagus, and yet we know that the normal function of the vagus, as set into action by the first movement of swallowing, is to carry out a peristaltic contraction of the œsophagus. We believe that just as at the beginning of the alimentary canal there is a gradual transition from the cerebro-spinal reflex of swallowing to the local intestinal reflex of peristalsis, so at the lower end of the gut there is a change in the reverse direction from the automatic reflexes of the upper part of the colon to the spinal reflex which in defæcation affects the lower segment of the large intestine. The control of the central nervous system is therefore limited to the two ends of the alimentary canal. The experiments of Goltz, however, on the effects of extirpation of the lumbo-sacral cord seem to imply that the autochthonic mechanism of the small intestine is not entirely absent even in the hindmost segments of the gut, and that these, when entirely and permanently cut off from spinal control, may after a time develope powers little inferior to those of the small intestine.

We may mention in conclusion that on no occasion have we observed any result on any part of the large intestine from stimulation of the vagi or the splanchnic nerves.

II. The large intestine of the rabbit.

The methods adopted in this investigation were practically identical with those employed in the case of the dog. The enervation was however always carried out by destruction of the cord from the sixth dorsal nerve downwards, the friable vessels in this animal not allowing of the thorough dissection necessary for the destruction of the abdominal plexuses. The rabbits were anæsthetised with ether, with or without a preliminary injection of morphia. The intestines were exposed in a warm saline bath, and the movement recorded by the insertion of a balloon connected with a registering piston recorder.

Superficially there is a great contrast between the large intestine of the rabbit and that of the dog, but this difference is conditioned mainly by the much greater activity of the former.

Local reflexes. On exposing the colon of the rabbit in the warm bath, some time after destruction of the lower part of the cord, it is found as a rule to be in a state of activity, the intestine being pouched out at intervals by the small scybala which are characteristic of many herbivorous animals. Above each dilatation is a constricted ring which advances gradually down the intestine, pushing the fæcal pellet in front of it. Several of these advancing peristaltic contractions may be present at the same time within a length of 10 or 12 inches of gut. If for any reason the onward progress of a pellet is prevented, the intestine continues in a state of increased activity just above the pellet, and this state is often not abolished by the arrival of a peristaltic wave from above. On introducing the recording balloon into the gut it almost immediately sets up a state of excitation which extends over several centimetres of gut above the balloon and rapidly drives this out through the opening by which it was inserted. If the expulsion of the balloon be prevented by tying it to the intestinal wall, strong waves of constriction starting above the balloon pass down over it and are recorded as rhythmic contractions by the piston recorder. If the balloon be inserted in a collapsed condition, the intestine may suffer its presence for some time, but a distention of the balloon evokes at once a peristaltic contraction and consequent expulsion of the balloon. If the balloon be inserted from above, the effect of the peristaltic contractions starting above the balloon, since they cannot force the balloon downwards, is to pull all the relaxed portion of the intestine from the lower to the upper end of the balloon, so that one or two feet of intestine may lie in folds on the three inches of tube passing from the balloon to its orifice of insertion.

This extreme excitability of the intestinal wall makes it very difficult to demonstrate by the graphic method the presence or absence of an ascending excitation as the result of a local stimulus. Although such an effect is always produced, it is difficult in the tracing to dissociate it from the large rhythmic contractions already excited by the presence of the balloon. The effect however is so obvious and so easily evoked that a graphic record is unnecessary. If the spinal cord of a rabbit be destroyed, and the colon exposed in a warm saline bath, a local stimulus to any part invariably excites a contraction which, commencing one cm. above the excited spot spreads over two or three cm. and then travels slowly down the intestine as a peristaltic wave.

The presence of a descending inhibition is however much more difficult to demonstrate. If the intestine be pinched between the fingers, the wave of contraction starting above travels down over the stimulated spot even during the continuance of the stimulation. This difficulty in the demonstration of a descending inhibition is due in the large as in the small intestine to the limitation of the process both in time and extent. Every local stimulation produces a condition of inhibition which extends at the most two or three cm. below the excited spot and lasts only a few seconds, in fact, for the space of time generally occupied by one of the larger rhythmic contractions of the gut (Fig. 7).

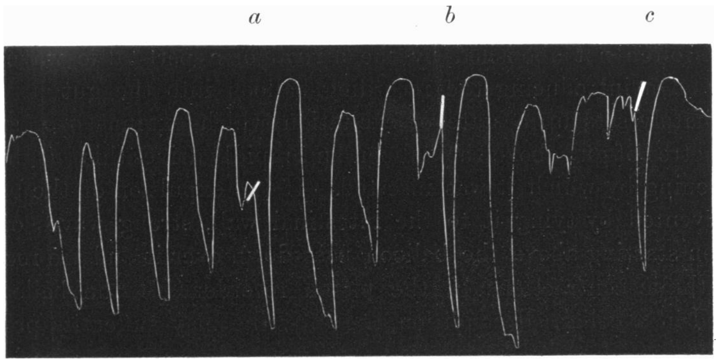

Fig. 7. Rabbit. Colon. Showing descending inhibition. Cord destroyed from 6th thoracic. Balloon introduced from above. The marks at *a*, *b*, and *c*, indicate stimulation by pinching the intestine above the balloon.

The nature of this descending inhibition is shown in Fig. 7. Here stimulation produced by pinching the gut one cm. above the balloon

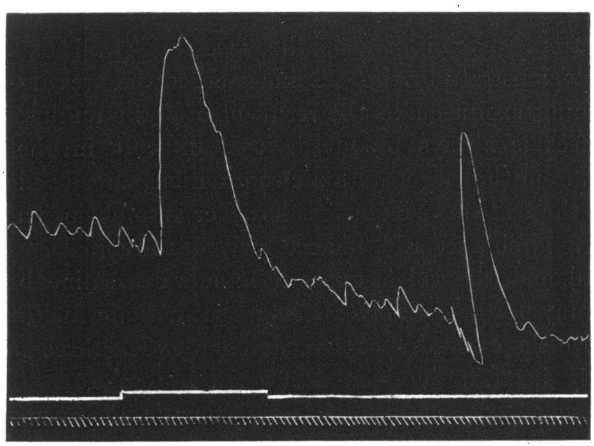

Fig. 8. Rabbit. Colon. Stimulation of pelvic nerve, and spontaneous peristalsis. Time marking = 2 seconds.

causes in every case an immediate relaxation of the intestinal muscle at whatever point in the curve the stimulus is applied. The inhibition is not however a lasting one, and therefore is not distinguishable in form on the tracing from the ordinary remissions of activity which alternate with the rhythmic contractions. The presence of an inhibition over a short area immediately in front of each descending wave of contraction is well shown in the spontaneous contraction represented at the end of the tracing in Fig. 8.

We may conclude therefore that the mechanism of peristalsis in the colon of the rabbit is essentially the same as in the small intestine of the dog, *i.e.*, a co-ordinated peripheral reflex. The differences being connected with the fact that the peristaltic activity in the rabbit is continuous, whereas in the dog it is occasional.

Extrinsic innervation. The action of the efferent nerves which pass to the colon of the rabbit may be considered very shortly, since they exactly resemble those in the dog. The pelvic visceral nerve is a pure augmentor nerve. Stimulation of it causes a contraction of the whole of the colon, often especially marked where the intestine

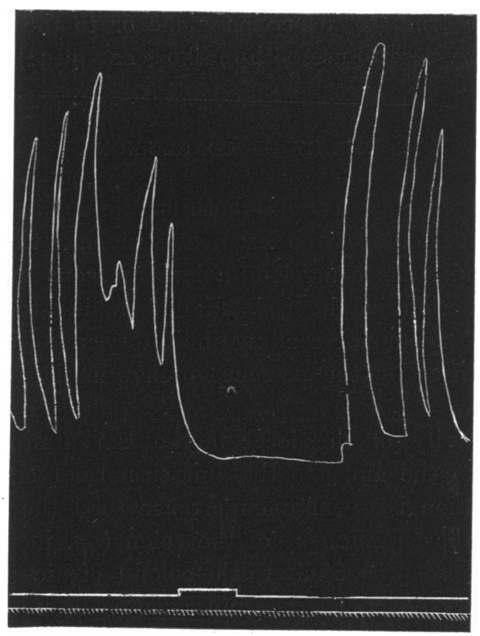

Fig. 9. Rabbit. Colon. Stimulation of colonic splanchnics. Time marking = 2 seconds.

is already excited by the presence of a fæcal pellet or a recording balloon.

No trace of an initial inhibition is ever observed in the rabbit as the result of stimulating this nerve. As in the dog, the pelvic nerve soon shows signs of fatigue. This facility of fatigue is probably connected with the fact that in all our experiments we have excited the preganglionic fibres of these nerves.

The mesenteric nerves or colonic splanchnics always excite inhibition of the muscular coats of the colon. We have under no circumstances been able to obtain any motor effect from these nerves, although in some cases, when the activity of the intestine has not been as marked as usual, we have noticed an improving effect of the stimulation on the subsequent contractions. It is possible that the motor effects which have been described as the result of exciting these nerves may be due to the fact that the inhibition which is the immediate result of the stimulation has not been noticed on mere inspection, and the after effects of the inhibition have been regarded as the direct action of the nerves. Indeed the extreme activity of the intestines of the rabbit and their liability to spontaneous variations of activity render it absolutely necessary not to trust to inspection alone or to the graphic method alone, but in every case to use both methods as mutual controls.

Summary of conclusions.

The following conclusions apply both for the dog and the rabbit:

(1) The movements of the large intestine, like those of the small intestine, are under the control of a local nervous mechanism. The peristaltic contraction in the isolated gut is due to combination of ascending excitatory and descending inhibitory impulses started in the local nerve plexuses by the presence of a stimulating agent in the lumen of the gut.

(2) The activity of the local mechanism diminishes from the ileocæcal valve to the anus, so that under normal circumstances the extrinsic innervation is of more importance than the intrinsic in the emptying of the lower segment of the colon (*e.g.* in defæcation).

(3) The sympathetic supply to the colon (colonic splanchnics) have a purely inhibitory effect on both muscular coats of the bowel. The pelvic visceral nerve is motor to both coats.